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Title: Advancing microbiome research

Author: **Julian R. Marchesi**

Professor of Human Microbiome Research at School of Biosciences, Sir Martin Evans Building, Museum Avenue, Cardiff University, Cardiff, And

Professor of Clinical Microbiome Research and Deputy Director at the Centre for Digestive and Gut Health, QEOM Building, St Mary's Hospital, South Wharf Road, Imperial College London, London

Correspondence address

Professor of Human Microbiome Research at School of Biosciences, Sir Martin Evans Building, Museum Avenue, Cardiff University, Cardiff, CF10 3AT

Email: MarchesiJR@cardiff.ac.uk

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The advent of new high throughput sequencing technologies has made a fundamental contribution to how we define the extent of the microbial world. In combination with other molecular tools and novel imaging platforms, we can now define many roles that microbes play without even the need to culture them in the laboratory. From the combined application of these platforms we have begun to develop new evolutionary ideas such as the holobiont concept, in which the host's genomes and the metagenome have coevolved [1] and this concept has led to a discussion on the validity of the idea [2]. The area in which it has probably made the most significant impact is in human biology, and to a lesser extent mammalian biology.

In the past decade, we have begun to re-evaluate human biology and have realised that microbes have a role to play at all levels. However, including the interactions of the host microbiota leads to a significant increase in the complexity of the system, which in turn can lead to data overload. Therefore, if we are to realise the potential of integrating the host's microbiome into a more holistic model, we will need to engage with a wider range of data scientists and engineers to help us identify the important signals within all the noise. Furthermore, we will need to undertake a robust revision of what these microbes are doing in the host and which functions are responsible for modulating the host physiology and biology.

We are currently facing a deluge of data and at times it is difficult to see the wood for the trees; therefore future projects will need to be multidisciplinary and consider involving big data scientists, where they will be able to bring artificial intelligence tools to bear on the problem and identify patterns of variables which we can link to host/environmental features. Building interdisciplinary research capacity, skills and infrastructures are recommendations made by the Microbiology Society's *Unlocking the Microbiome* science policy report, launched in November 2017 [2], which was informed by a series of workshops in the UK and Republic of Ireland, and an Expert Working Group. This expert group identified the opportunities and challenges of microbiome research for health, agriculture, environment and biotechnology. The report made 10 recommendations for

researchers, industry, policy-makers and other research stakeholders to progress microbiome research (Table 1).

Additionally, we need to develop better cross-pollination between the different subdisciplines within the field of microbiome research, to prevent each subdiscipline reinventing the wheel. So, going forward we will need to rationalise the data that we generate to identify key functions that we can target and manipulate to provide better outcomes for the host. For example, how do the microbes in the gut control and interact with lymphocytes to ensure that more patients with cancer respond to either chemotherapy or immunotherapy?

In the future, we will also need to educate not only university students, but also the wider public to the importance of looking after your different microbiomes, and how by doing so you can improve your health and well-being. To this effect, the Microbiology Society and the British Society for Immunology have collaborated on a joint retrospective cross-portfolio collection of articles published across the society journals to allow easy access to research in this area. These microbiomes will not just be local, i.e. gut or skin, they will also be environmental, in soil and oceans. The more we know about microbiomes the more we realise how important they are in nearly every facet of our lives from personal health to food security and global ecosystem function.

Conflicts of interest : The author declares that there are no conflicts of interest.

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1. van de Guchte M, Blottière HM, Doré J. Humans as holobionts: implications for prevention and therapy. *Microbiome* 2018; **6**:81 <https://doi.org/10.1186/s40168-018-0466-8>
2. Foster KR, Schluter J, Coyte KZ, Rakoff-Nahoum S. The evolution of the host microbiome as an ecosystem on a leash. *Nature* 2017; **548**:43–51.
3. Microbiology Society. Unlocking the microbiome : opportunities and challenges of microbiome research for health, agriculture, environment and biotechnology. 2017. Available at <https://microbiologysociety.org/microbiome>

Table 1: Recommendations in the Microbiology Society's Unlocking the Microbiome report [Adapted from reference 3]

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| Building the evidence base | Researchers should work with funders to enable support for large-sample and longitudinal studies so that researchers can validate associations, identify biomarkers and assess the long-term implications of human or environmental changes to microbiomes. |
| Interdisciplinary research and knowledge exchange | In order to optimise the benefits of this important area of research, which is inherently interdisciplinary, funders and learned societies |

should work together to facilitate community-led collaborations that are:

- Multidisciplinary – joining disciplines such as microbiology and biochemistry with clinicians, social scientists and a wide range of other professionals.
- Cross-cutting – linking experts in human, animal and environment microbiomes.
- Effective at local, national and international levels.

Building research capacity

Recognising the central importance of research related to microbiomes, and the specific skills required to maximise its potential, science educators need to develop targeted early career training and education in areas such as bioinformatics and basic microbiology skills.

The scientific community should support workshops, training networks and infrastructure for established research groups to develop and gain access to required resources.

Sharing data and resources

All relevant sectors of the scientific community should commit to collaborating to establish rigorous standards for data access and interoperability

Funders and the research community should discuss how to effectively and efficiently manage data for the long term, so that maximum benefit can be derived from well maintained and curated databases.

Best practices and standards

The international microbiome research community, funders, publishers and regulators should work together to agree standards.

Facilitating translation

In order to accelerate translation, public and private sector research funders should focus on facilitating academic–industry collaborative networks, such as BBSRC Networks in Industrial Biotechnology and Bioenergy (BBSRC NIBB) and Science Foundation Ireland Innovation Centres.

In order to facilitate translation whilst ensuring consumer protection, policy-makers and regulators should prioritise closer and earlier collaboration with end-users to ensure the development of appropriate regulations for microbiome interventions and products.

Microbiome Research and Society

Those involved in microbiome research should work with policy-makers, educators, journalists and the public to ensure that the potential of this emerging

science and innovation is communicated accurately, people are enabled to make informed decisions and scientists are always regarded as a trusted source of information.
